Seismic retrofit design and durability improvement of roads and highways structures in Japan

Tatsuya-Suzuki,Toshimi-Takeda,Yuhiko-Watanabe,
Masahiro-Hasegawa,Yoshimi-Takeda,Yasuyuki-Suzuki
Committee member of Japan Civil Engineering Consultant Association
Chiyoda Engineering Consultants
3-57-5 Nishigahara Kitaku Tokyo Japan
t-suzuki@chiyoda-ec.co.jp

ABSTRACT

In Japan a lot of seismic retrofit design and durability improvement projects are being carried out. Many projects are being conducted yearly by 23 roads and highways structure technical committee companies of the Japan civil engineering consultants association. This report presents analytical results and design example selected from the work of 23 companies, as well as a summary on current seismic performance improvement and durability improvement measures of roads and highways structures and related issues through engineering consultants' perspective.

In this report, projects being conducted domestically are classified into three distinct fields, which are planning and design of durability improvement and maintenance, durability improvement of existing structures, and durability improvement through seismic retrofit. The report then introduces outstanding examples of each field by presenting background information on defect condition, their seismic retrofit design, as well as the design codes and theories used in each project.

1. INTRODUCTION

Nowadays in Japan bridges with more than 50 years of age are becoming functionally old. The Japanese social and economic scene has changed. Strict situation in economic scene is continuing. In this situation it is more important than ever to operate and maintain effectively the existing social assets.

About 19,000 bridges are maintained and repaired by Ministry of Land, Infrastructure, Transport and Tourism (MLIT). 40% of them were constructed during the years of rapid economic growth. The ratio of bridges with over 50 years old and all existing bridges will become 10% in 2010 and will become 50% in 2050. In other words, almost one-half the total number of bridges will age over 50 years old by the year 2030.

Similar to the bridges owned by MLIT, bridges owned by prefectural governmental authorities are expected to face the same problem. Together with increase of numbers of new bridges, a lot of bridges in Japan are becoming functionally old.In the ongoing financial difficulties, it is expected that maintenance and renewal of bridges become major social burden.

From these backgrounds, it is important to cut down Life cycle cost (LCC) of existing bridges and to make use of durability improvement methods in designing and planning stages of new bridges in order to reduce their life cycle cost.

In Hyogokenn-nannbu earthquake in 1995, bridges designed using specifications prior to the 1980 specifications were heavily damaged by the earthquake. On the basis of this experience, earthquake resistant design and unseated prevention method are being constructed for substructure of high degree of urgency bridges in which possibility of secondary damage is expected.Also, for river bridges and road bridges which are subjected to conditions that make constructions difficult and are designed by using earlier specifications than 1980's specifications, necessary seismic proof construction are being carried out.

From now on, it is important that seismic performances of the existing bridges are investigated and for bridges which maintenances are required, constructions are carried out quickly and efficiently.

In Japan, improvements of seismic performance has become an important issue, so it is advantageous that examples of improvements are collected and analyzed. Therefore, Road and structure committee of JCCA collected examples of seismic performance improvement works of bridges and classified them by 3 perspectives, which are “planning and designing of durability improvement”, “maintenance”, “durability improvement of existing structures”, and “durability improvement through seismic retrofit”. This paper describes typical examples among each field.

2. The effects of salt corrosion on a concrete bridge

Typical determining factors in reinforced concrete structures and pre-stressed concrete structures are; neutralization, salt damage, alkali aggregate reaction, frost damage and fatigue deterioration. Fatigue deterioration is caused by several, complicated reasons. These include the natural environment around the building, the weight force against the structure and the materials used in the construction of the building. Salt damage is influenced by the natural environment around the site where the structure is built. A crucial factor is the level of salinity in the air. The level of corrosion on the reinforcing bars and pre-stressed concrete steel advance when chloride ions permeate through concrete. Cracks and flaking in the concrete are caused by the expansion of corrosive factors in the concrete steel. This phenomenon leads to a reduction in the quality of the structure as a result of salt damage.

Japan is an island nation, surrounded by four oceans. The measures taken against salt damage are the important factors in the structural plan, when considering the durability of concrete structures. This important topic is described as “The investigation of durability” in The Specification for Highway Bridge, III concrete bridges and IV substructure.[1] [2] The description in III concrete bridges is shown below (Figure1) (Table1).

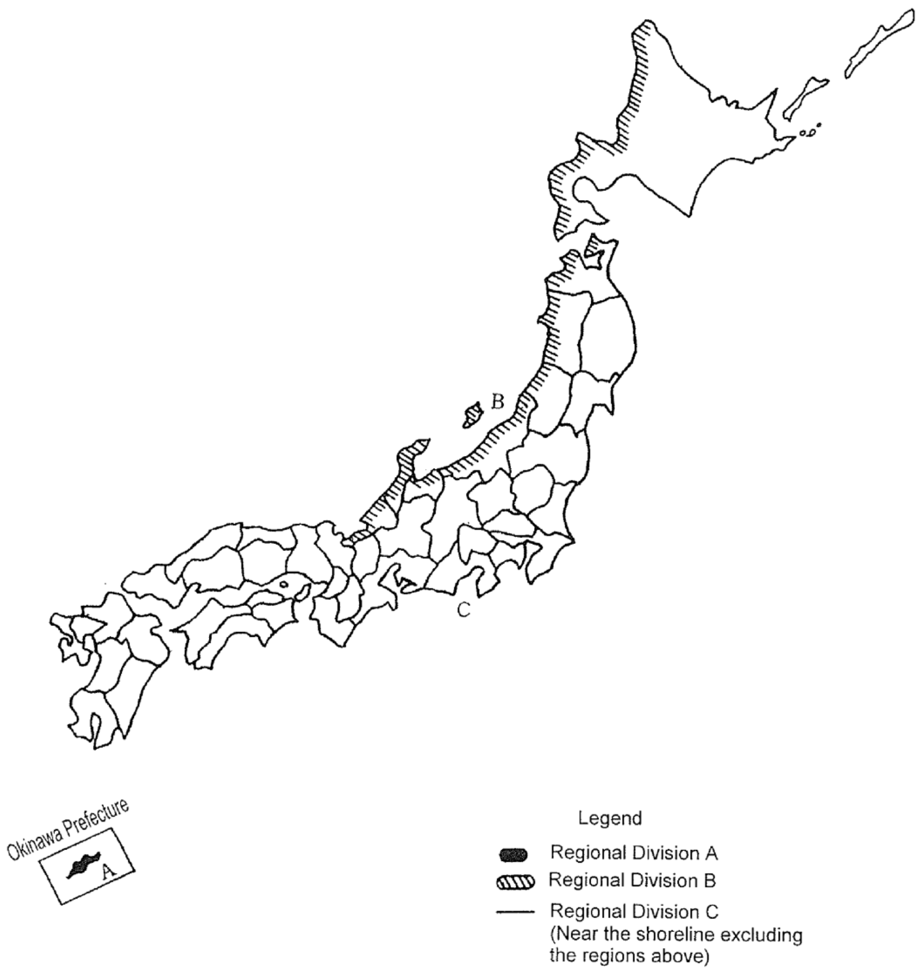


Figure 1 Regional divisions based on the severity of salt damage. [1]

Table 1 Regions affected by severity of salt damage .[1]

Regional division	Region	Distance from shoreline	Severity of salt damage and class of measures	
			Class of measures	Severity
A	Okinawa Prefecture	Above sea level and up to 100 meters from the shoreline	S	Severely affected
		Exceeding 100 meters but up to 300 meters	I	Affected
		Range other than the above	II	
B	Regions shown in Figure 5.2.1 and Table 5.2.3	Above sea level and up to 100 meters from the shoreline	S	Severely affected
		Exceeding 100 meters but up to 300 meters	I	Affected
		Exceeding 300 meters but up to 500 meters	II	
		Exceeding 500 meters but up to 700 meters	III	
C	Regions other than the above	Above sea level and up to 20 meters from the shoreline	S	Severely affected
		Exceeding 20 meters but up to 50 meters	I	Affected
		Exceeding 50 meters but up to 100 meters	II	
		Exceeding 100 meters but up to 200 meters	III	

A design case with measures taken against salt damage.

A pre-stressed concrete continuous long span box girder bridge is built above the Japanese ocean, and breaks the spray caused by ocean waves to great effect. Therefore, the effects of steel corrosion by salt permeation were considered for the long-term future. In this design case, the level of salinity in the air and the amount of salinity infiltration in the environment are investigated. A control agent against chloride penetration was painted on the surface wherever the amount of steel material corrosion was expected to exceed 1,2 kg /m3 during the service period. This was intended to improve the long term durability of the structure.

To investigate salt damage, the level of salinity in the air was measured at the site of the bridge (Figure2). The examination body was collected from the actual bridge. Then the amount of salt adhesion on the examination body surface was measured. The test results, when considered synthetically, determined where on the span the measure needed to be applied. The amount of salt infiltration was able to be estimated using Fick's first diffusion formation. When considering the landscape, impregnation materials were chosen for the measure. With reference to other test results, alkali-alkoxysilane materials were chosen because of their effectiveness at intercepting salt infiltration. The quality of the material confirmed how effective it was against the concrete strength of the actual structure. For further confirmation, tests on infiltration depth, the intercept effect for salinity infiltration and an accelerated weathering test (equal to approximately 10 years under external conditions) were conducted. The results showed that the measure performed well under laboratory conditions.

To decide when it would be necessary to repaint again in the future, an examination piece of same strength concrete with silan paint was made. This examination piece was placed on a pier and collected constantly to allow a survey on the levels of salt permeation. Through an analysis of concrete from the pre-built steel surface of a pre-stressed concrete girder, the level of salt permeation was assessed. Fick's first diffusion formation was applied to the result. It was estimated that the steel material would begin to corrode where the amount of salt on steel surfaces exceeded 1.2kg/m^3 (Figure3). It was also estimated how long it would take for this process to begin.

As the result of using these measures, salt infiltration through concrete structures in the natural environment where salt damage could occur, was controlled. This was proven to be a measure of high durability. Through an analysis of the examination body the appropriate repainting time was concluded.

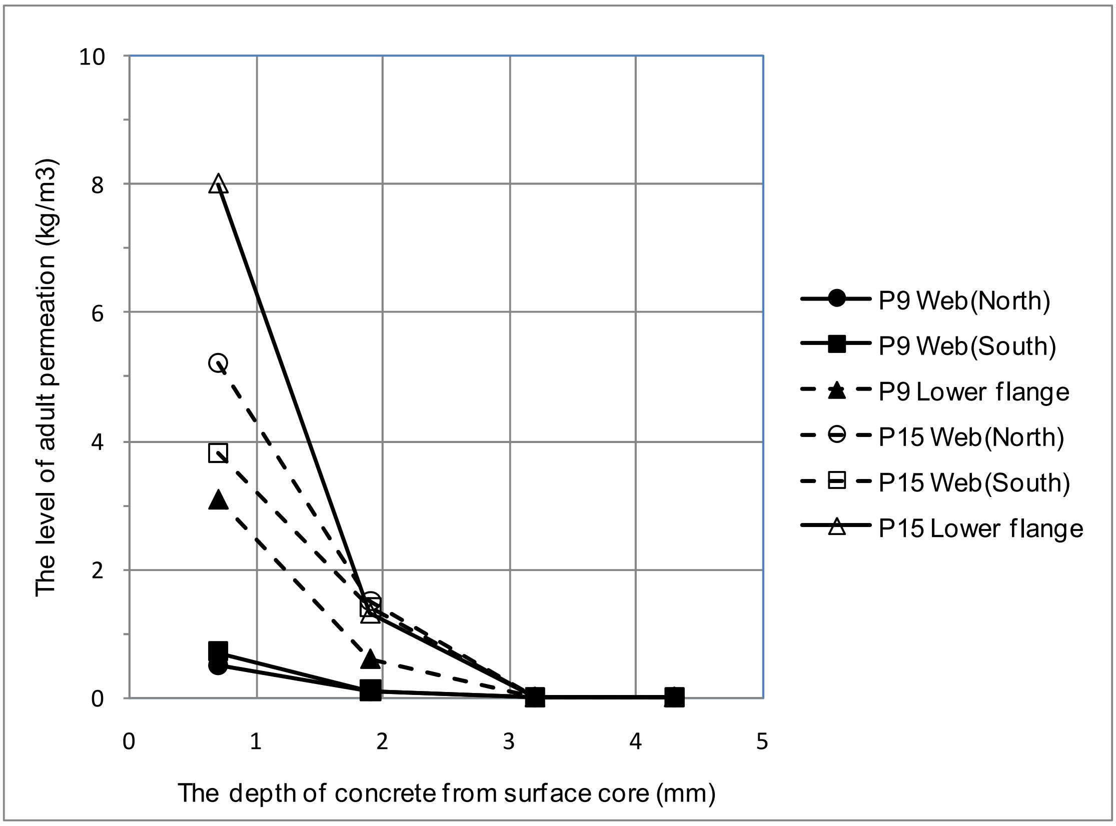


Figure 2. Result of investigation on salt damage.

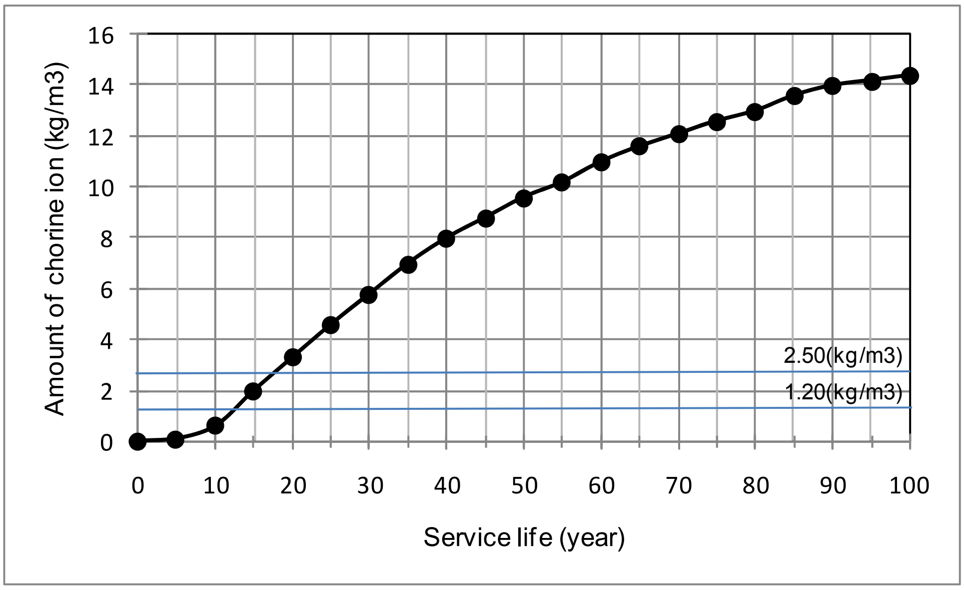


Figure 3. Graph relating amount of chorine ion to service life.

3. The continuous of bridges

When a newly-established bridge is planned, it is often the case adopted continuous girder bridge, because it excels in economy, travelling performance of vehicle, environmental, resistance to earthquake and the maintenance management side. Previously, in many cases the simple girder bridge was adopted, but it has the following problems.

- The noise and vibration induced by an expansion joint, debasement of a traveling performance of vehicle.
- The regular maintenance of an expansion joint and paving is necessary.
- It offers lower resistance to earthquakes than a continuous girder bridge.

The continuance of the existing bridge is being carried out to improve above problems. There are the following design cases in the continuous method for the main beam.

- Steel simple girder bridge : Web is connected with by the clip.
- PC simple girder bridge : A cross beam is connected with PC tendon
- Others : The continuance of the PC hinge rigid-frame bridge. The continuance of the Gerber bridge.

There are many cases that the influence spreads the whole of the bridge, because this structure changes induced by this method.Because of that, it is abundantly seen when the checking of not only the joint member but also the main beam, the substructure and foundation is necessary, and those reinforcement. Moreover, when fitted a reinforcing member on the existing member, the details analysis is necessary, because a local stress sometimes occurs. In the case of a construction for existing bridge, it is important that cordon off spacing of member and working space, and must figure out fully the condition of the existing bridge.

This structure is the PC hinge box rigid-frame bridge, which 26 years passed after the completion of construction. In this case, the central hinge has become depleted by the increase of the live load in recent years, creep deformation and friction.
As for this bridge, the debasement of a performance of vehicle and the maintenance of the hinge were weak point. The continuous of central hinge by outside cable and non-expansion apparatus carried out to improve these. Then, this bridge changed PC 3 spans hinge box rigid-frame bridge into PC 3 spans consecutive rigid frame box girder bridge.

- Length of bridge : L= 408.3m
- Span : before 129.4m+97.0m+91.0m +89.4m, after 129.4m+188.0m+89.4m
- Structure : before PC 3 spans hinge box rigid-frame bridge, after PC 3 spans consecutive rigid frame box girder bridge
- Steel material for the reinforcement : outside cables 19S15.2B (epoxy coating type) × 8

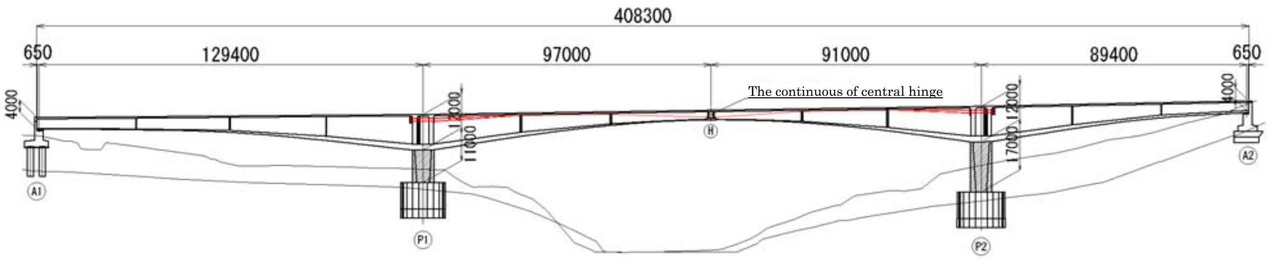


Figure 4. The edge view of the bridge

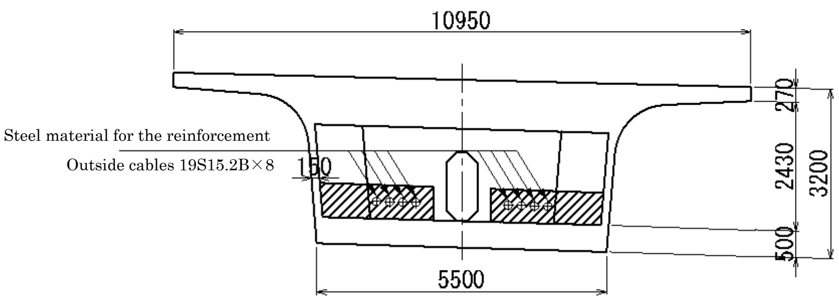


Figure 5. The cross section of the bridge

The bridge could not find acceptable value of tensile stress at the central hinge and the A1-P1 side span, because the structure changed and the live load increased. (=the B live load) As a result, it arranged effectively eight outside cables (19S15.2B), and could find acceptable value of tensile stress and degree of bending destruction safety but did not apply adhesive steel plate and adhesive method of carbon fiber seat.

The arrangement of outside cable fixation part and deviation part compared distributed arrangement to centralized arrangement, and adopted reasonable distributed arrangement. The fixation part and deviation part putted existing fulcrum and middle cross beam to practical use, and led to abatement of dead load and advancement of construction. When these were reinforced with outside cable, three-dimensional FEM analysis with solid member was carried out and checked safety of this structure, because a local stress due to prestress load added.

The structure of central hinge change, but the value of plus bending moment is relatively small. Then, the reinforcement with outside cable is effective.   As for DYWIDAG, it is different that the distributed arrangement is adopted, because many PC steel rod is arranged. It is advisable that outside cable fixing point put existing cross beam to practical use and reduce possibly the increase of dead load. When the deviation part was fitted on the existing middle cross beam, the arrangement of outside cable is freer, and the design is economic.

4. Extended slab method

The Expansion joints of highway bridges absorb displacements of structures by temperatures and live loads. There are members of bridges which improve driving performances of cars at edge of the girders. The type of expansion joints is elaborated based on amount of flexibility. There are rubber butt joint, rubber and the steel finger joint and modular type (joint) that cross beams placed and supported by bridge axis beams. Larger flexibility of expansion joint is required because of that more continuous girders and more lengthening span of bridge are trends of these days. The structural members are going to be enlarged as mentioned tendency. Whereas the report on events of deformation and damage by its fatigue have been increasing. The expansion joints are antithetic structures for the continuousness of structures. Faulting near the expansion joints become causes of low frequency, noise and vibration.

The problems concerning the expansion joint are shown in the following.

- Running cars on the joints make impact vibrations. The vibrations are passing through piers and reaching houses nearby.
- Running cars on the joint make the noise of structure.
- Running cars on the joint make pumping noises. Since above events occurred, no joint structure in recently is advanced.

Design cases of removing expansion apparatus and extending slabs.

Deicing salts corrode joint expansion apparatus in cold districts. And the corrosions leak rainfalls. In addition to the leakage, deicing salts corrode steel girders and bearings, too. There disruptive effects of deicing salts are very concerned for durability of operation and maintenance of the bridges. The extending slabs that are expected as deterioration measure of the structure by leakage from expansion joints are shown here.

- Bridge length：L＝138.55m
- Span：45.70m+46.15m+45.70m
- Superstructure：Three continuous span non-synthetic steel girder bridge

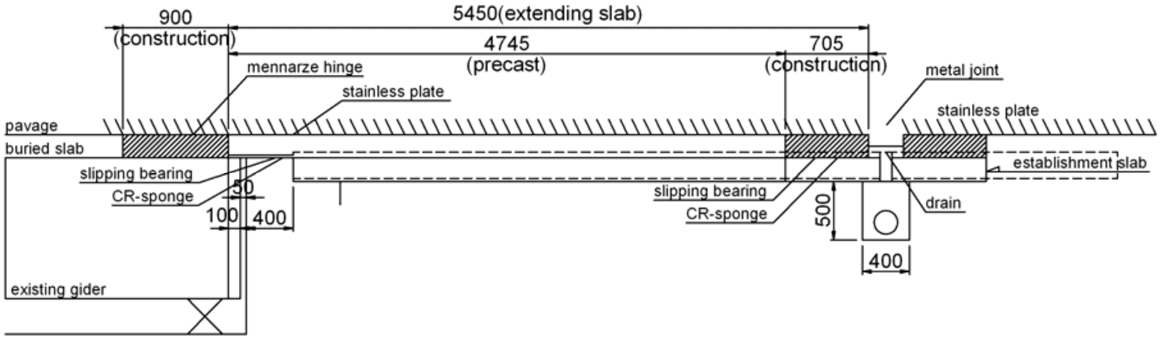


Figure 6. The briefing view of the extended slab

The length of extending slab was assumed to be 5.0m to provide function as approach cushion slab. The extending slab was designed a simple beam of reinforced concrete which a parapet and an approach cushion slab are made fulcrum. Extending slabs may be prefabricated in a fabrication yard nearby. High early strength cement was used for the slabs. The site joint was made a loop joint. The loop joint was placed the in-situ concrete, and integrated. As a result, shortening the site term of works and the improvement of the quality were aimed at. Rubber bearing for the extending floor slab support is set up on the parapet and the approach cushion slab. The stainless plate with the slipping function was set up between this rubber bearing and the extending floor slab. Sand and the waterproofed CR sponge for were set up in the bearing surroundings. And also the drainer is set up beside extending slabs and release rainfalls to drain. To rotate a girder, a mennarze hinge was assumed to joint of an existing slab and an extending slab. Rubber buffer was set up in the joint. Rainfalls leaking from joints flow to drain and perforated tube underground. In addition, the waterproofing was constructed under the pavement.

5. The seismic retrofit design

In most cases of the existing bridges in Japan are not designed based on the concept of required seismic performance at the time. Therefore, it is an issue which performance should be taken for the bridges to be seismically retrofitted. It is also necessary to consider the damage extent, service life and time of reconstruction in the determination of the seismic performance to be guaranteed.

In the concept of the seismic retrofit design it is basically considered the safety of the pier for a large scale earthquake can be guaranteed ensuring energy absorption by natural period lengthening when it deforms within a range in which its resistance would never be rapidly reduced even if it deforms plastically beyond elastic limit. This ductile strength of a member in a range of the plastic deformation is called “ductility”.

Thus it is important to develop a retrofit plan in the seismic design assuming appropriately the resistance and deformation performance of the pier.

Fundamentals of seismic design

- Avoiding brittle failure by means of ductile structure.
- Avoiding loss of bridge functions due to unseating of superstructure during an earthquake. In addition keeping its function and repairability after an earthquake.

Fundamentals in seismic retrofit

It is a basic principle to establish a ductile structure improving ductility to prevent a shear failure. However, in most practical cases it is not sufficient only with ductility improvement. In this case the anchor should be provided in the foundation footing to enlarge the lateral strength and ductility capacity. Thus, in the resistance reinforcement, excessive reinforcement of bending strength in piers may lead to a reduction of deformation capacity (allowable ductility μa). Additionally it enlarges retrofit scale so that the sectional force in the foundation will be increased respectively. Therefore it is preferable to reinforce exclusively insufficient bending resistance improving the ductility as possible.

In seismic retrofit design, the buckling out of the longitudinal rebar and the failure of core concrete, should be prevented. For this purpose it is important to provide the appropriate arrangement of the stirrupps and confining rebars and also constructive details for the expected ductility.

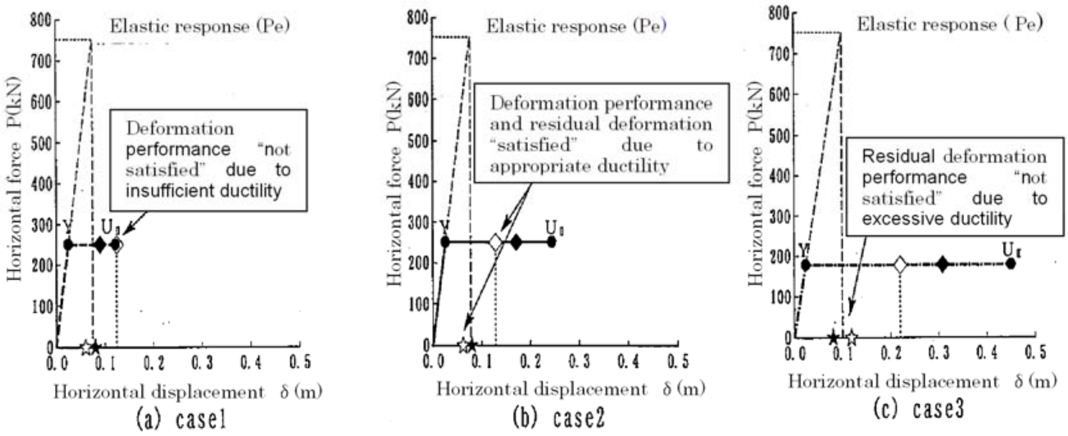


Figure 7. Response displacement of a Pier

Generally a plastic hinge should be assumed in the bottom of the existing pier to ensure enough ductility. Therefore, when the cut-off the longitudinal reinforcement at mid-height is provided in the existing bridge, there should be reinforced not to be failed before the bottom. In this case this area at mid-height should be reinforced covering the required range in accordance with the pier shape.

This example shows the seismic retrofit by means of the steel plate with improved atmospheric corrosion resistance covering the cut-off reinforcement area. The bridge is located on the steep slope in a moutain area so that a huge maintenance cost such as a scaffolding for repainting after the reinforcing could be expected. Thus this type of steel is applied for the reduction of maintenance cost.

- Bridge length : L＝192.55m
- Span : ℓ ＝ 37.0m+37.0m+37.0m+43.0m+37.0m
- Superstructure : Continuous Steel I-girder Bridge(2spans), Continuous Steel I-girder Bridge(3spans)
- Substructure : Reinforced Concrete Pier
- Foundation : Deep Foundation , Spread Foundation

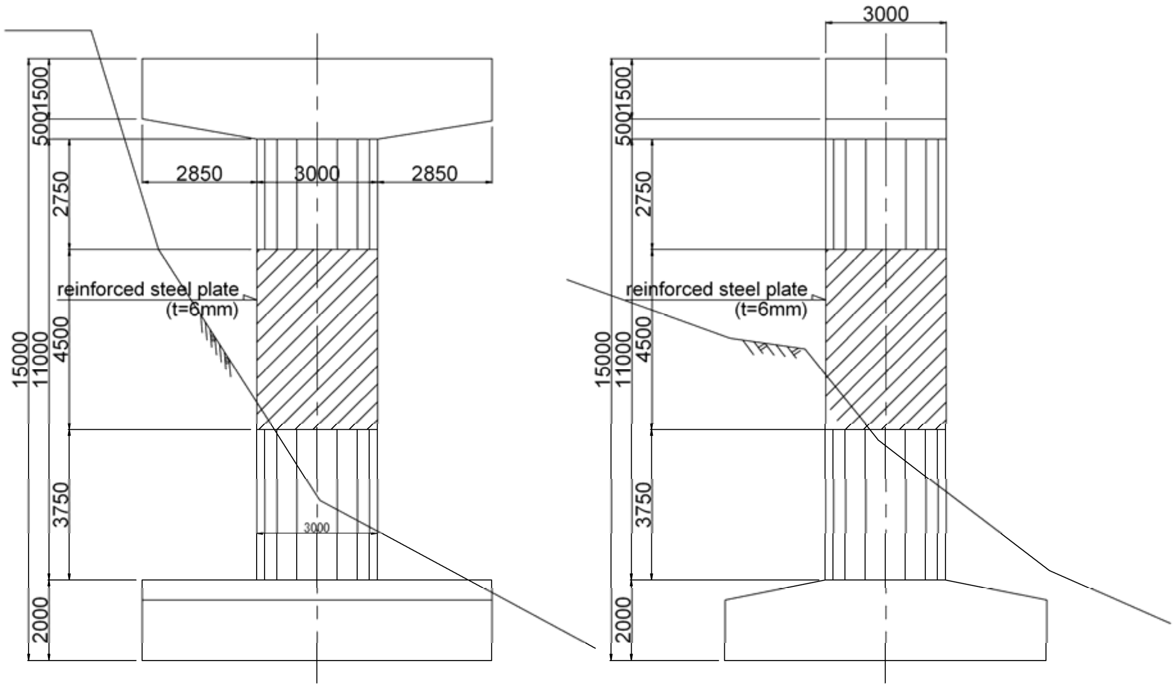


Figure 8. The structural view of the pier

The steel with improved atmospheric corrosion resistance is a type of steel includes alloys such as Cu, Cr, Ni etc. It makes the development of the fine rust(stable rust) due to repetitive humidity in the atomoshere. This steel surface is protected with the stable rust and prevented the progressive rust or corrosion. Stable rust is developed normaly in 1 to 5 years and offers outstanding anti-corrosive performance. Therefore, it is frequently applied in the bridge structures today from the viewpoint of life cycle cost. However, attention need to be paid for its environment as the stable rust would not be developed where air is not likely to flow.

Normal structural steel used for the retrofit covering piers need to be maintained for repainting once for 10 years. In this example maintenance cost is drastically reduced dispensing with repainting using the steel with improved atmospheric corrosion resistance for this retrofit construction.

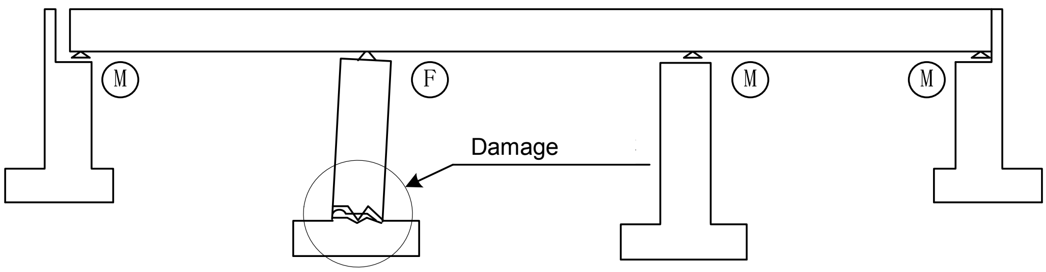
6. A method of inertia force dispersion

A method of inertia force dispersing is how to contribute the inertia force caused by earthquake to each substructure. Accordingly, it as a whole can resist inertia force and bear destruction. Several methods of that are provided such as using rubber bearing shoe, designing multi-fixed support, and the damper stopper, etc. And according to the situation, a superstructure is designed as a continuous method of superstructure.

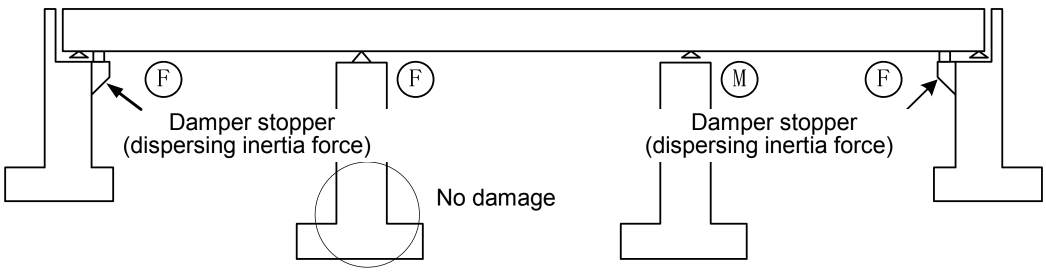
In this design case, the decrease of inertia force is aimed at the damper stopper, and the aseismic capacity for the total bridge system has been improved. Moreover, the cost of the aseismic reinforcement work on the bridge was decreased. In Japan, as a way of countermeasure for a large scale earthquake (level 2), RC covering method is generally chosen. But in this case, the structural type of this bridge is multi-span continuous beam and its shoes adopt rubber bearings. Consequently it is estimated that this bridge's quality against the earthquake is high. That situation suggests us that if existing bearing can be used effectively as it stands there might be a low cost method.

As a result, the method which combines damper stoppers with existing bearings (rubber bearing) was adopted, and inertia force generated by earthquake can be decreased.

Setting up the damper stopper, the balance of the inertia force that is distributed to each substructure is changed by "Effect of the by-pass of inertia force". Therefore the capacity of the damper stopper is tuned up carefully based on the nonlinear dynamic analysis.



(a) Structure before it has antiseismic reinforcement



(b) Structure after it has antiseismic reinforcement

Figure 9. A briefing view of the aseismic reinforcement by the method of inertia force dispersing

- Bridge length：L=632.55m
- Span length：59.7m+6@29.0m+6@31.5m+33.84m

The damper stopper was set taking into account the seinsmic deformation and temperature elasticity. Moreover, the capacity of the damper stopper was set to handle the shear distortion of rubber bearing, the flexural capacity. and the shear capacity of the pier in a acceptable value. In this bridge designing, the nonlinear dynamic analysis is adopted.

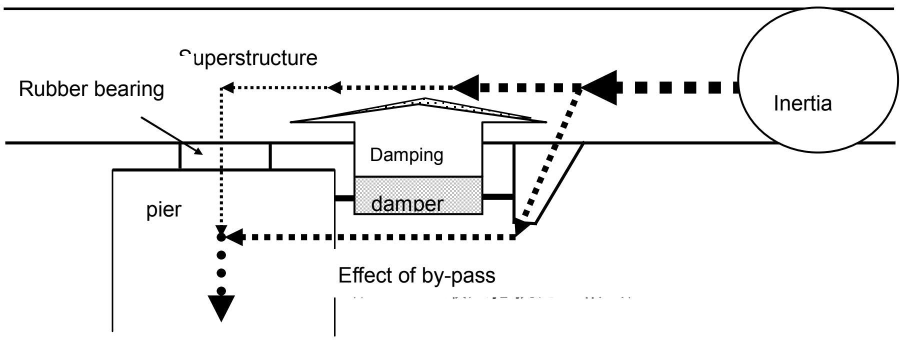


Figure 10. Concept in effect of by-pass

The following opinions were obtained from this aseismic reinforcement design.

- The amount of aseismic reinforcement on the pier was decreased because the damper stopper was set up and therefore the costs were reduced.
- It is necessary that the power should not act at a perpendicular direction to the bridges axis of the damper stopper .
- The change of transmission mechanism must be observed carefully as the axial rigidity of the damper stoppage is larger than the sheer rigidity of the rubber bearing.

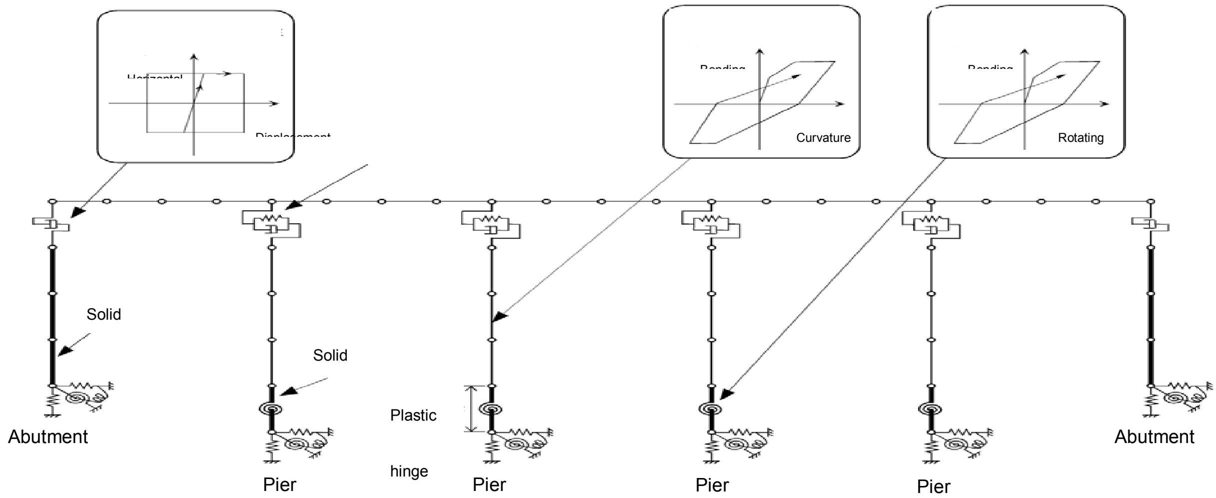


Figure 11. The briefing view of model

7. CONCLUSIONS

There is a necessity to cut back on lifecycle cost of bridges by carrying out the failure prevention and the maintenance. It becomes more and more necessary that existing bridges are maintained according to plan by means of seismic performance improvements and maintenance, and asset management methods that would enable life extension of the bridge.

I hope that this paper gives helpful contributions to future maintenance of bridges in Asian countries.

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